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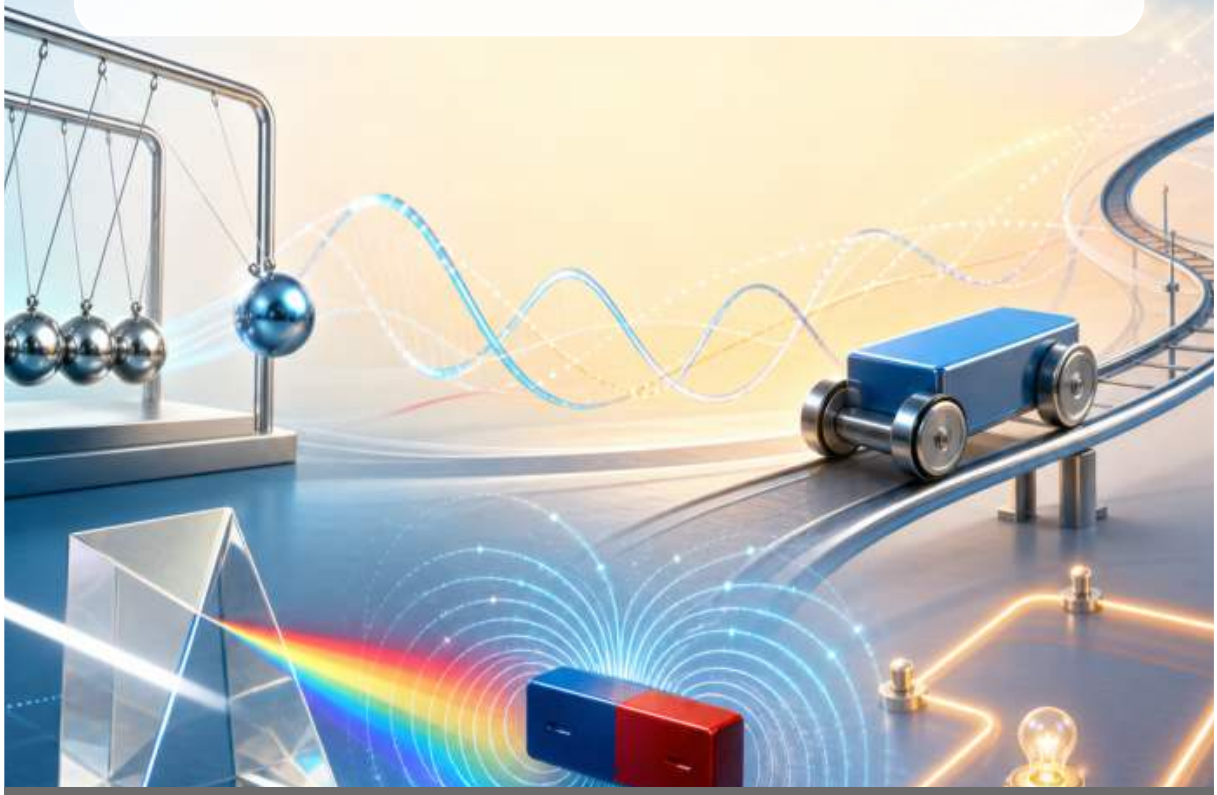
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Reza Nazari

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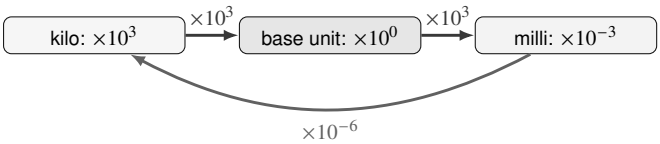
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Scientific models in this book are simplified when that helps a beginner see the central relationship. Each simplification is identified in the lesson and should be used within its stated assumptions. Electrical and radiation topics are for education; they are not instructions for working on household wiring, high-voltage equipment, or radioactive materials.

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The amount stays the same while the numerical value changes. A smaller unit requires more units: 1 m = 1,000 mm.

A **conversion factor** is a ratio of equal quantities, so its value is one. Arrange the ratio so the unwanted unit cancels:

$$2.40\,\text{km}\left(\frac{1{,}000\,\text{m}}{1\,\text{km}}\right) = 2.40 \times 10^3\,\text{m}.$$

The units guide the setup. If the unwanted unit does not cancel, the conversion factor is upside down or does not belong.

Example 1

Worked Example: Convert a road speed

☞ **Represent.** A car's speed is 72.0 km/h. The target unit is m/s.
Relate. Use the exact relationships 1 km = 1,000 m and 1 h = 3,600 s. Arrange each factor to cancel the original unit.
Calculate.

$$72.0\,\frac{\text{km}}{\text{h}}\left(\frac{1{,}000\,\text{m}}{1\,\text{km}}\right)\left(\frac{1\,\text{h}}{3{,}600\,\text{s}}\right) = 20.0\,\text{m/s}.$$

Check. Kilometers and hours cancel, leaving the requested unit of m/s. Also, $20.0 \times 3.6 = 72.0$, so converting back recovers the given speed.
Interpret. At this speed, the car covers 20.0 m each second.

20.0 m/s.

Squared and cubed units

When a unit is squared or cubed, the conversion factor must be squared or cubed too:

$$1\,\text{cm}^2 = (0.01\,\text{m})^2 = 10^{-4}\,\text{m}^2, \qquad 1\,\text{cm}^3 = (0.01\,\text{m})^3 = 10^{-6}\,\text{m}^3.$$

This matters in later calculations involving area, volume, pressure, density, capacitance, and light intensity.

Units as an error detector

A physically meaningful equation combines compatible quantities. The relationship $d = vt$ passes a unit check:

$$\frac{\text{m}}{\text{s}} \cdot \text{s} = \text{m}.$$

The expression $d = v + t$ fails because speed and time describe different kinds of quantities and cannot be added.
The meter and kilometer are different *units* for the same kind of quantity: length. A unit is the chosen measuring scale. A **dimension** identifies the kind of quantity being measured. In dimensional notation, length is $[L]$, time is $[T]$, and force has dimensions $[MLT^{-2}]$. Matching dimensions are necessary for an equation to be possible, but they do not prove that its numerical factor, sign, or physical model is correct. Because $1\,\text{J} = 1\,\text{N m} = 1\,\text{kg m}^2/\text{s}^2$, energy has dimensions $[ML^2T^{-2}]$. Torque has the same base dimensions as energy even though torque and energy describe different physical quantities.
Use three checks:

1. **Cancellation:** Do the unwanted units cancel?
2. **Target unit:** Does the result have the requested unit?
3. **Equation:** Do both sides describe the same kind of quantity?

A conversion that cannot work

The setup

$$5.0\,\frac{\text{m}}{\text{s}}\left(\frac{3{,}600\,\text{s}}{1\,\text{h}}\right)\left(\frac{1{,}000\,\text{m}}{1\,\text{km}}\right)$$

multiplies meters by meters. The second factor must be $\frac{1\,\text{km}}{1{,}000\,\text{m}}$ so meters cancel. The repaired result is $18\,\text{km/h}$.

1.4 Practice: Conversions

1. Convert 3.50×10^2 cm to meters.

   A $0.350\,\text{m}$ **B** $3.50\,\text{m}$
   C $35.0\,\text{m}$ **D** $3.50 \times 10^4\,\text{m}$

2. Which factor converts seconds to minutes while canceling seconds?

   A $\frac{60\,\text{s}}{1\,\text{min}}$ **B** $\frac{1\,\text{s}}{60\,\text{min}}$
   C $\frac{60\,\text{min}}{1\,\text{s}}$ **D** $\frac{1\,\text{min}}{60\,\text{s}}$

3. Which conversion factors equal one? *Select all that apply.*

   - ☐ **A.** $\frac{100\,\text{cm}}{1\,\text{m}}$
   - ☐ **B.** $\frac{1\,\text{h}}{3{,}600\,\text{s}}$
   - ☐ **C.** $\frac{1{,}000\,\text{g}}{1\,\text{kg}}$
   - ☐ **D.** $\frac{1\,\text{m}}{1\,\text{s}}$

4. A student converts $90.0\,\text{km/h}$ to meters per second using $\frac{1{,}000\,\text{m}}{1\,\text{km}}$ and $\frac{3{,}600\,\text{s}}{1\,\text{h}}$. Explain the time-factor error and give the corrected speed.

1.5 Scale, Scientific Notation, and Measurement Quality

Scientific notation makes physical scale easier to see. It writes a nonzero value as $a \times 10^n$, where $1 \le |a| < 10$, and the exponent records the decimal-point shift. Thus,

$$0.000\,42 = 4.2 \times 10^{-4}.$$

When n is positive, 10^n is greater than one, so the value is larger in magnitude than its coefficient. When n is negative, 10^n lies between zero and one, so the value is smaller in magnitude than its coefficient.

Powers of ten also support quick estimates. A classroom door is about $2\,\text{m} = 2 \times 10^0\,\text{m}$ tall. An estimate of $2 \times 10^3\,\text{m}$ would describe a height of two kilometers, so it fails before any detailed calculation begins. This kind of scale check catches misplaced decimals and inverted conversion factors.

Entering scientific notation on a calculator

Use the calculator's `EXP` or `EE` key when it is available. To enter 4.50×10^{-4}, type 4.50, press `EXP` or `EE`, and enter -4. Do not multiply by another 10 after using the exponent key.

Example 2

Worked Example: Write a small time in scientific notation

☞ Move the decimal four places right to make a coefficient between 1 and 10:

$$0.000450\,\text{s} = 4.50 \times 10^{-4}\,\text{s}.$$

The exponent is negative because the original value is less than one second. The trailing zero remains because it carries measurement information.

Toolkit check. The new notation changes the written scale, not the time that was measured.

4.50×10^{-4} s.

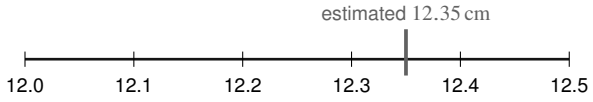
Resolution, uncertainty, accuracy, and precision

These ideas answer different questions:

Idea	Central question
Resolution	What is the smallest change the instrument displays or marks?
Uncertainty	What range of values is reasonably supported?
Accuracy	How close is the result to a true value or a well-supported reference value?
Precision	How closely do repeated measurements agree?

Resolution is the smallest change in the measured quantity that produces a perceptible change in the indication. A digital balance that shows two decimal places has a display increment of 0.01 g, but the display increment alone does not establish the instrument's accuracy or total measurement uncertainty. A ruler marked every 1 mm has marked divisions of 1 mm = 0.1 cm.

An analog scale may support one estimated digit beyond the markings when the mark spacing, object edge, and viewing conditions make that estimate meaningful. This book will state when that convention is being used. Otherwise, report to the stated instrument resolution. The final digit should communicate what the reading supports, not the number of digits a calculator can display.



Example 3

Worked Example: Report a ruler reading with uncertainty

☞ The smallest marked division is 0.1 cm, and the block ends halfway between 12.3 cm and 12.4 cm. Under the stated estimated-digit convention, the reading is 12.35 cm. For this example, half of the smallest marked division is used as a simple uncertainty estimate:

$$L = (12.35 \pm 0.05)\,\text{cm}.$$

Subtracting and adding 0.05 cm gives an interval from 12.30 cm to 12.40 cm. This classroom estimate reflects the ruler markings. Other laboratories may base uncertainty on repeated trials, calibration data, or instrument specifications, so follow the stated convention. The interval communicates uncertainty. It does not by itself establish accuracy. Writing 12.35000 cm would claim detail the ruler cannot support.

$L = (12.35 \pm 0.05)$ cm, supporting 12.30 cm to 12.40 cm.

Accuracy concerns closeness to a true value or a well-supported reference value. **Precision** concerns agreement among repeated measurements. A tightly clustered set can be precise but inaccurate if a calibration problem shifts every result. Trial-to-trial scatter contributes random uncertainty. A consistent calibration shift is a systematic effect. Repeating a measurement helps reveal random variation, but repetition alone does not remove a systematic shift.

2. A position–time line rises 18 m during 6 s. What is its slope?

A 3 m/s
B 12 m/s
C 24 m/s
D 108 m/s

3. Which SI base-unit expression has the dimensions of force?

A $\mathrm{kg\,m/s^2}$
B kg/s
C $\mathrm{m^2/s}$
D $\mathrm{kg\,m^2/s^2}$

4. If north is positive, which value describes a 7 m displacement south?

A +7 m
B −7 m
C 0 m
D 14 m

5. Which are scalar quantities? *Select all that apply.*

- ☐ **A.** displacement
- ☐ **B.** mass
- ☐ **C.** speed
- ☐ **D.** force

6. Which practices improve a graph-based physics analysis? *Select all that apply.*

- ☐ **A.** Read both axis labels and units.
- ☐ **B.** Assume every rising line means acceleration.
- ☐ **C.** Calculate slope from two well-separated points on a straight best-fit line.
- ☐ **D.** Check whether an intercept has a physical meaning.

7. A value is written as 3.6×10^5 Pa. Write it in ordinary notation.

8. Explain why a precise set of measurements can still be inaccurate.

9. Convert $2.50 \times 10^2\ \mathrm{cm^2}$ to square meters.

A $2.50 \times 10^{-4}\ \mathrm{m^2}$
B $2.50\ \mathrm{m^2}$
C $2.50 \times 10^{-2}\ \mathrm{m^2}$
D $2.50 \times 10^{6}\ \mathrm{m^2}$

10. Which result has the same physical dimensions as energy?

A N m
B N/m
C kg m/s
D W/s

11. An analog ruler is marked every 0.1 cm. A block's edge lies halfway between 12.3 cm and 12.4 cm, and the instructions require one estimated digit beyond the markings. Which reading follows that convention?

A 12.347821 cm
B 12.3 cm
C 12 cm
D 12.35 cm

12. A wire is 45 μm thick. What is this thickness in meters?

A 4.5×10^{-7} m	**B** 4.5×10^{-6} m
C 4.5×10^{-5} m	**D** 4.5×10^{5} m

13. A graph has vertical units of newtons and horizontal units of meters. What are the slope units?

A N m	**B** m/N
C N/m	**D** N/s

14. Two perpendicular displacement vectors are 3 m east and 4 m north. What is the resultant magnitude?

A 1 m	**B** 5 m
C 7 m	**D** 12 m

15. An estimate for a classroom door's height is most reasonably

A 2×10^{-3} m	**B** 2×10^{0} m
C 2×10^{3} m	**D** 2×10^{6} m

16. A model is fitted to measurements from 0 s through 5 s. Using it to predict a value at 8 s is an example of

A calibration	**B** interpolation
C unit conversion	**D** extrapolation

17. Which checks can reveal a calculation error? *Select all that apply.*

- ☐ **A.** Verify that units combine to the requested unit.
- ☐ **B.** Compare the magnitude with a rough estimate.
- ☐ **C.** Ignore a negative sign whenever the answer seems inconvenient.
- ☐ **D.** Substitute the result back into the original relationship.

18. Which quantities require both magnitude and direction? *Select all that apply.*

- ☐ **A.** time
- ☐ **B.** temperature
- ☐ **C.** velocity
- ☐ **D.** acceleration

19. Convert 54.0 km/h to meters per second.

20. A delivery robot travels 0.360 km west in 2.0 min. Choose east as positive. Give the two position–time endpoints in SI units, calculate average velocity in m/s with justified significant figures, convert its magnitude to km/h, interpret the sign, and include one reasonableness check.



A final toolkit check

Rebuild Question 45 without looking at the worked examples, then use the checks below to decide whether your result is physically sensible.

Representation: known values, directions, units, and endpoints _____

Relationship and calculation: equation, substitutions, and result _____

Checks and interpretation: unit, sign, size, precision, and meaning _____

Use the open workspace for a diagram, conversion chain, calculation, or revised explanation. Keep units and labels visible.

